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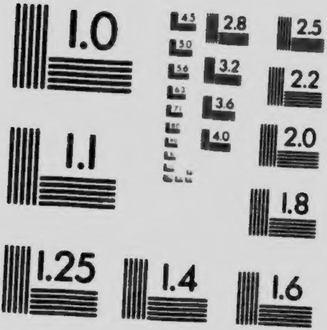

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ON AN IMPROVEMENT IN THE METHOD OF DETERMINING MINIMUM SPARK POTENTIALS

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On an Improvement in the Method of Determining Minimum Spark Potentials.

By H. S. FIERHELLER, B.A.Sc.

(Communicated by Professor J. C. McLennan, and read before the Royal Society of Canada on May 26, 1909.)

Spark discharge in gases has long commanded the attention of investigators and from the experimental data which has been accumulated, especially through the researches of Paschen,[1] Peace,[2] Strutt,[3] Carr,[4] and others, the general laws governing such discharge have come to be fully established and widely known.

The mechanism of such discharge, especially under certain definite conditions, has also been the subject of a minute enquiry by Townsend [5] and has been shewn by this investigator to be capable of a very simple explanation on the basis of the theory of collisions by gaseous ions.

Of the different phases of the spark discharge which have been studied, that dealing with the potentials required to produce spark discharges in gases at different pressures has been given the most careful attention.

It has been shewn when starting with a gas at atmospheric or higher pressures and a constant spark length that the sparking potential decreases as the pressure is lowered in such a way that the changes in the sparking potential are almost directly proportional to changes in the pressure of the gas, and further that as the pressure in the gas is progressively diminished the sparking potentials ultimately reach a minimum value at a certain critical pressure which varies with the conditions of the discharge. Further diminution in the pressure is always accompanied by a rapid increase in the magnitude of the sparking potentials. This relationship between the spark potentials and the pressure of a gas has been elaborately worked out by Carr (loc. cit) for uniform electric fields in air and other gases with different spark lengths, and a curve which is typical of his results and which illustrates the law of discharge under those conditions is shewn in Fig. III.

The results from which such curves are drawn have hitherto been obtained by exhausting the discharge chamber to different pressures, and then ascertaining by trial the voltage obtained from small storage cells or other equally steady sources of potential, which would be just sufficient to produce discharge.

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[1] Paschen, Ann. de Phys. Vol. 37, p. 69.
[2] Peace, Proc. Roy. Soc. Vol. 52, p. 99.
[3] Strutt, Phil. Trans. A. Vol. 193, p. 377.
[4] Carr, Phil. Trans. A. Vol. 211, p. 403.
[5] Townsend, Phil, Phil. Mag. (6) 6, p. 598, 1903.

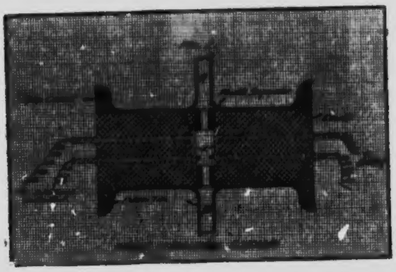
The well known phenomenon of delay in the passage of such discharges, which has been investigated at length by Warburg[1] and which is especially marked in the neighbourhood of the critical pressures where discharges are frequently not obtained until ten or fifteen minutes after the application of the requisite voltage, renders the process of taking readings an exceedingly laborious and tedious one.

The writer who had recently occasion to obtain such experimental curves during an examination of the spark potentials in different media found that they may be obtained with comparative ease and with a great reduction in time if the ordinary procedure be reversed and the sparking potentials ascertained by lowering the pressure until the applied potential will just cease to produce discharge instead of keeping the pressure constant and increasing the applied potential until it is just sufficient to break down the gas.

The following paper contains a short description of the manner in which the method was applied together with a few of the results obtained with discharges in air and hydrogen.

II.—*Apparatus and Method.*

The form of the discharge chamber used in the experiments is similar to that adopted in Carr's investigation, and is shewn in Fig. 1. The electrodes *c*,*d*, were supported by ebonite plugs and were kept separated by a disc of ebonite provided with small openings which permitted free communication between the air in the sparking space E and the leading tubes A and B. The electrodes *c* and *d* were hollow metallic boxes provided with inlet and egress tubes for the passage of heated liquids and were designed for the purpose of studying the relation borne by the sparking potentials to the temperature of the electrodes.



The exhaustions were made by means of a Toepler-Hagan mercury pump attached to the apparatus, and the pressures were determined from the readings of a McLeod pressure gauge.

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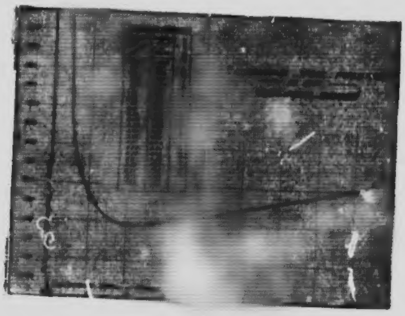
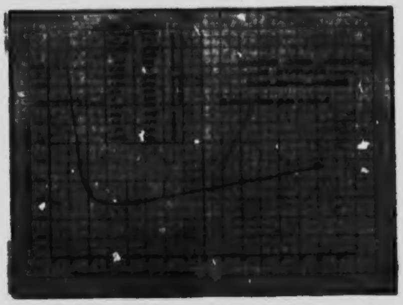
[1] Warburg, Ann. de Phys. Vol. 62, p. 385.

In using this apparatus after the manner of the earlier workers one of the electrodes *c* was joined to a quadrant electrometer or to an electrostatic voltmeter, diagram I, Fig. II, also initially earthed through a bye-pass key. The potential selected, which was obtained from a storage battery protected with a water or xylol resistance in circuit, was then applied to the electrode *d* and the earth connection to *c* broken. If no discharge occurred after waiting some minutes, higher and higher potentials were successively applied until discharge did occur. Generally this was indicated by a violent deflection of the electrometer or electrostatic voltmeter needle.



By following this method a series of spark potentials was obtained with the air at different pressures when the electrodes were 3.3 mm. apart. The values of these potentials together with their corresponding pressures and a curve to illustrate them are shewn in Fig. III. The lowest sparking potential, it will be seen, [illegible] obtained at a pressure of about 2.3 mm. of mercury and amounted to [illegible] 388 volts. This potential, (and in fact all the potentials for the different pressures investigated with air), was somewhat higher than the number obtained by Carr under similar conditions. This discrepancy, however, was considered to be due to differences in the air in the two sets of measurements. In Carr's measurements care was taken to have the air both clean and dry but in the present experiments no particular steps were taken to clean and dry the air in which the sparks took place. After taking the measurements in air the apparatus was thoroughly washed out with pure and dry hydrogen and a second set of spark potentials taken for different pressures in this gas. The results are given in the Table in Fig. IV and a curve illustrating them is shewn in the same figure. This curve as well as the results which it represents, is practically identical with that deduced by Paschen's Law from Carr's numbers, and in view of this agreement it was concluded that all the conditions of the experiment were suitable for making a test of the modification in the method of procedure referred to above.

The manner in which the modification was applied is illustrated by diagram II in Fig. II.



As the diagram shews, one terminal of the battery of storage cells was joined to earth and the other to the junction of a divided circuit. One of the branches of the divided circuit led to the terminal of an electrostatic voltmeter which accordingly gave the voltage of the cells. The other branch of the circuit included a high reading Weston voltmeter possessing a resistance of 65,000 ohms, a Weston milliammeter, and the spark gap.

In making the measurements the voltage from the battery was first applied to the circuit and then the pressure in the discharge chamber was reduced until discharge occurred. When this happened the passage of the current was indicated by both the Weston milliammeter and the Weston voltmeter and the reading on the electrostatic voltmeter gave the potentials at the terminals A and B of the discharge chamber circuit.

Care was always taken by altering the number of cells in the battery, as required, to see that the electrostatic voltmeter readings remained constant over the whole range of pressures.

A measure of the current passing through the discharge chamber could be obtained from the readings on either of the Weston instruments, but owing to a difference in the sensibility of the two instruments the milliammeter was used to obtain approximate readings and the voltmeter when accuracy was required.

In making the observations a voltage sufficiently high to cause a discharge to take place was first applied and then the pressure in the discharge chamber was gradually lowered and at various stages the pressure in the discharge chamber ascertained from the corresponding reading on the McLeod gauge.

Sets of such readings were taken in hydrogen for 400, 500, 600, 700, and 900 volts, and the various current and pressure readings corresponding to each of these potentials are recorded in Table I. Curves illustrating these readings are also shewn in Fig. V.

From these curves it will be seen that with each voltage the current over a limited range of pressures was practically constant, but that below this range the current fell away as the pressure was lowered and ultimately dropped to zero at a certain definite pressure for each voltage. This drop in the current indicated of course that the resistance of the spark gap increased as the pressure was lowered. As the conductivity of the circuit apart from the spark gap remained constant for all pressures, this rise in the resistance of the gap was therefore accompanied by a corresponding rise in the potential difference between the two electrodes in the discharge chamber. It follows then that when the current ceased to pass the potential difference between the electrodes was the same exactly as that which was supplied by the battery and was measured by the electrostatic voltmeter reading. We have then in these final current readings a means of ascertaining the pressures at which the different applied voltages ceased to cause current to pass, or what is practically the same thing, the spark potentials corresponding to different pressures in the discharge chamber.

TABLE I

CONDUCTIVITY OF HYDROGEN.

Applied E. M. F. 400 volts.			Applied E. M. F. 500 volts.			Applied E. M. F. 600 volts			Applied E. M. F. 700 volts			Applied E. M. F. 900 volts.		
Pressure millims. mercury	Conduc'y v.m. indications	Current amperes x 10^{-3}	Pressure millims. mercury	Conduc'y v.m. indications	Current amperes x 10^{-3}	Pressure millims. mercury	Conduc'y v.m. indications	Current amperes x 10^{-3}	Pressure millims. mercury	Conduc'y v.m. indications	Current amperes x 10^{-3}	Pressure millims. mercury	Conduc'y v.m. indications	Current amperes x 10^{-3}
7.11	98	1.5	14.55	175	2.5	9.66	268	4	9.66	362	5.5	11.0	580	9.0
5.77	96	1.5	11.77	170	2.5	7.88	270	4.1	7.94	360	5.5	8.88	580	9.0
4.66	90	1.5	9.55	167	2.5	6.44	270	4.1	6.44	357	5.5	7.11	563	8.7
3.77	85	1.3	7.66	158	2.5	5.33	260	4	5.05	343	5.2	5.77	515	8.5
3.11	75	1.1	6.22	153	2.3	4.22	243	3.7	4.22	328	5	4.77	527	8
2.44	55	.9	5.0	145	2.0	3.44	220	3.2	2.77	288	4.3	3.95	506	7.9
1.8	..	..	4.11	138	2.0	2.88	185	2.5	2.22	270	4	3.16	480	7.5
....	..	..	3.33	125	1.9	1.93	93	1.5	1.5	180	2.9	2.55	453	7
....	..	..	2.66	101	1.5	1.6	...	...	1.25	...	...	2.11	425	6.5
....	..	..	2.11	72	1.1	....	....	...	....	...	...	1.66	375	5.8
...	..	..	1.88	25	.5	....	....	...	....	...	...	1.44	166	2.5
....	..		1.70	..			...	...	...	..	...	1.1	..	..

From the form of the current curves for the different voltages it is easy to deduce the pressures corresponding to zero currents. These zero-current pressures for the different potentials are collected and given in column I of Table II, and in column III of the same table the spark potentials as deduced from the experimental curve in Fig. III are also given. From a comparison of the pressures in column I with those in column III it will be seen that the numbers are practically the same, which goes to show that the modification here outlined for determining sparking potentials is equally reliable with that formerly followed. The chief advantage possessed by this method over that formerly used is that the spark potentials are obtained by following the variations in a perfectly definite phenomenon, namely the strength of the current passing through the discharge chamber, whereas with the older method, the information sought for was obtained by a series of slow and tedious trials with potentials extending over a range whose limits were gradually brought more and more together.

TABLE II

HYDROGEN

From conductivity curves Fig. 4		From spark potential curve Fig. 4
Pressure for Minimum conductivity	Applied E. M. F. or spark potential (volts)	Pressure in mm. mercury
1.85	400	1.8
1.78	500	1.6
1.58	600	1.5
1.3	700	1.3
1.1	900	1.1

From the preceding description it is obvious that the gradual diminution of the pressure in the discharge chamber when the current was passing could only lead to the determination of spark potentials which lie on that branch of the curve in Fig. III below the critical pressure.

The spark potentials corresponding to pressures above the critical pressure may, however, be ascertained by the same method if a gas be admitted instead of withdrawn from the discharge chamber when the current is passing. Such a procedure was adopted in the case of hydrogen in the present enquiry for the potentials 350 and 400 volts. The various readings taken are recorded in Table III and curves drawn from them are shown in Fig. VI. From these curves it will be seen that for 350 volts the zero-current pressure in the upper range is 8.22 mm. of mercury and for 400 volts 11.1 mms. of mercury. These pressures are practically the same as those which may be deduced from the experimental curve in Fig. III, and it follows therefore that the method is applicable to the determination of spark potentials in any gas in the range above as well as in that below the critical pressure.

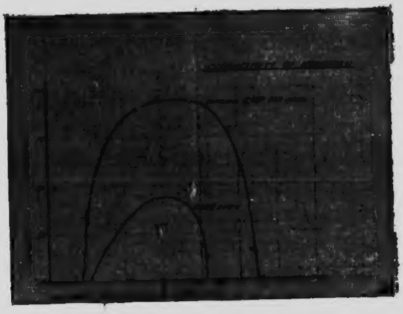


TABLE III

Applied E. M. F.	400 volts	Applied E. M. F.	350 volts
Pressure Millims mercury	Conductivity Voltmeter indications	Pressure Millims mercury	Conductivity Voltmeter indications
1.8	0	2.11	0
2.0	30	2.44	5
2.45	55	3	10
2.77	50	3.22	15
3.11	75	4.11	35
3.77	83	4.77	45
4.66	90	5.44	38
5.77	95	6.88	38
7.11	95	7.33	40
7.88	88	7.66	45
8.88	83	8.2	18
9.55	80	8.22	0
10.3	30	....	..
11.1	0	....	..

In the experiments which have been described all the exhaustions were made by means of a Toepler-Hagan pump and the gas was admitted to the chamber by opening a tap in a tube leading to a supply of hydrogen.

The introduction into the laboratory of a Gaede exhausting air pump during the investigation, however, suggested at once the superiority of this piece of apparatus over the older form of pump for the purposes of the present investigation.

For with this pump the gas could not only be easily and rapidly withdrawn from the discharge chamber but it could also by a reversal of the pump's action be just as easily and with full control be again admitted back into the chamber.

TABLE IV

Above Critical Pressure

Pressure in mm.	Current in amperes x10-3 $\frac{\text{V. M. readings}}{\text{Res. of V. M.}}$	P. D. across spark gap	Minimum sparking potential
9	2.45	335	380
..	4.1	330	....
..	8.9	325	....
Below critical pressure			
2	.38	375	....
..	3.87	450	350
..	6.38	485	....
1.5	2.8	520	500
....	5.24	560	....

A point of special interest in connection with the present investigation is the confirmation it affords of some conclusions drawn by Mr. J. A. Brown[1] from his measurements on the potential required to maintain a current in a gas. With the arrangement described above the difference between the Weston voltmeter reading and that of the electrostatic voltmeter for a selected current gave a measure of the corresponding potential drop in the balance of the circuit which included the milliammeter, the connecting wires, and the spark gap. As the resistance of the connecting wires and of the milliammeter was small the drop in potential corresponding to these would be negligible, and consequently, the differences in the potential readings mentioned would represent the potential required to maintain the current selected in the spark gap.

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[1] Brown, Phil. Mag., Sept., 1906.

A few results bearing on this point have been calculated from the measurements of this investigation and are collected in Table IV.

The first of these corresponds to a pressure of 9 mm. in the discharge chamber and two others to pressures of 1.5 and 2 mms. respectively.

As the critical pressure in hydrogen with a spark gap of 3.3 mm. was between 3 and 4 mm. of mercury, the first of the pressures selected was therefore in the region below and the other two in the region above the critical pressure.

Column I of Table IV contains the pressures. Column II the corresponding sparking potentials, column III current readings deduced from the Weston voltmeter readings, and Column IV the observed potential differences which were found to maintain the currents between the electrodes in the spark gap recorded in the table.

From the numbers given it will be seen that in the region above the critical pressure a slight fall occurred in the potential between the electrodes when the current increased. In the region of pressures below the critical one, however, the opposite occurred, and the larger current intensities required the higher potential differences to maintain them.

These results are in keeping with those of Mr. Brown, who found that above the critical pressure the potential required to maintain a current dropped below the sparking potential and tended towards a limiting value which appeared to be independent of the current, while below the critical pressure the maintaining potential rose more or less rapidly above the sparking potential as the current increased in intensity.

In conclusion it is my pleasure to thank Professor J. C. McLennan for his kindly interest and valuable advice throughout the investigation.